WATER EXPECTANCY IN TUNNELS, MINES AND DEEP WELLS IN HOMOGENEOUS ROCKS

By Robert E. Horton

In planning deep subsurface structures such as tunnels and mines, it is desirable to form some idea in advance as to the amount of water which will probably be encountered and will require removal. Isolated test shafts are costly, and may not show average conditions. It is desirable to supplement such special data by considerations based on general experience as to the yield of underground water under similar conditions.

Data can generally be secured as to the yield of shallow or surface wells overlying the region where the underground structure is to be made. Such data have been published concerning many conditions and kinds of rock as to the average and usual range of yields of surface wells under different conditions.

It is the purpose here to present a method and formula by which data obtained from surface wells can be applied, under suitable conditions, to the estimation of the amount of water which it may reasonably be expected will be encountered in any deep excavation.

The method is limited to cases where the bed rock is somewhat uniform in character throughout all depths from the rock floor down to the bottom of the tunnel or other structure. For example, the method will apply to the estimation of probable water in a tunnel in granite, which extends to the surface, but will not apply to a tunnel in deep-seated granite overlain by thick beds of sedimentary rocks.

Without giving details it may be said that there are physical reasons, well confirmed by statistics and experience, showing that the frequency and water-carrying capacity of fissures, joint openings and solution channels in rocks decreases rapidly as the depth increases.

Assuming, for simplicity, and as fairly representing experience, that the water-yielding capacity of a given kind of rock varies inversely as the depth, and that q is the maximum yield per square foot of surface at a depth 0 to 1 foot below the water table. The

quantity q corresponds to Slichter's "transmission constant" and its value can be determined from the measured yield of shallow wells in the given location and kind of rock. Then the yield per square foot of surface at a depth h below the surface of the water table may be expressed by the equation

$$q_h = q/h \ldots\ldots (1)$$

The total yield from one side only of a vertical surface one foot wide intersecting the water bearing rock from a depth h_1 to a depth h_2 will be to

$$Q' = q_1 \int_{h_1}^{h_2} \frac{dh}{h} \ldots\ldots (2)$$

If p is the ratio of the perimeter of a tunnel to its height, or the ratio of the perimeter of a well to its diameter, then letting Q_1 equal PQ^1, where Q_1 is the total yield of a horizontal tunnel per foot of length, or the total yield of a well between any chosen depths per foot diameter, there follows by intergrating

$$Q_1 = q_1 \, p \, (\log_e h_2 - \log_e h_1) \ldots\ldots (3)$$

If it is desired to determine the total yield of a well from surface to bottom, h_1 should be taken as unity to correspond to the conditions assumed in fixing the value of q_1.

As a practical example, statistics gathered by E. E. Ellis, M. L. Fuller and others show the average yield for numerous shallow wells, on steep rocky areas, in granitic gneiss and schist of southeastern New York and Connecticut, to be about 4 gallons per minute for 6 inch wells with an average depth in rock below the water table of about 150 feet. The perimeter of a 6-inch well is 1.54 feet and the corresponding rate of yield for a flat surface one foot wide and 150 feet deep would be 2.60 gallons per minute. Solving (3) for q_1 under these conditions:

$$q_1 = \frac{2.6}{\log_e 150} = 0.52 \text{ gallon per minute}$$

It should be noted that only wells with little cover of sand or other unconsolidated material have been considered in selecting the value of Q_1 to determine q_1. Shallow wells in rock but with

deep cover of loose material often receive much of their supply from above the rock, and may indicate water quantities in excess of the transmission capacity of the rock itself, even at the surface where it is most fissured.

Let it be required to determine the amount of water that will probably be encountered in a tunnel 15 feet high and with 60 feet perimeter, at an average bottom depth of 250 feet below water table in granitic gneiss and schist, the length of the tunnel in rock being 11,000 feet. Using the value of q_1 above determined, and solving (3)

$$Q_1 = 0.52 \times 4 (\log_e 250 - \log_e 235) =$$
$$0.135 \text{ gallon per minute per foot of tunnel}$$

Let Q equal the total infiltration to the tunnel, the length being 1. Then $Q = Q_1L = 1485$ gallons per minute. This indicates that provision should be made to dispose of 1485 gallons per minute, or something over 2,000,000 gallons per day.

Experience in constructing the tunnel for which data are above given showed an average yield for some time of 1,000,000 gallons per day, and larger yields at times, approaching the amount above calculated.

Like most hydrologic methods and formulas, this one is not infallible, and its application requires intelligent discrimination in selecting surface-well data to determine q_1. It is intended to apply to fissured rocks such as granites, trap, basalt, gneisses, schists, and sometimes limestones and dolomites. It is possible that a large water vein may be encountered which will greatly increase the yield, but the probability of this decreases with increased depth.

In the case of unconsolidated materials and sandstones, the water transmission capacity may decrease little or none with increased depth, and formula (3) does not apply. The quantity of water obtainable from such deposits by means of wells, tunnels and infiltration galleries can be calculated by existing formulas given in various books on water supply.

In the case of shales, experience shows that the water-bearing fissures decrease very rapidly with increased depth, in fact little or no water is generally obtained in dense shales at depths more than 50 to 100 feet below the rock floor. Observations by the author in the case of many deep wells in Hudson River shale as to the relation of depth to yield is fairly represented by the formula

$$Q_1 = 2q_1 p \left(\frac{1}{h_1} - \frac{1}{h_2}\right) \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

This is derived on the assumption that both the number and size of connected fissures in shale decrease as the depth increases, or that the transmission capacity per unit of surface varies inversely as the square of the depth. For example, if a 6-inch well extending 20 feet below water table in shale yields 6 gallons per minute, then solving for q_1p in (4) by taking $h_1 = 1$ and $h_2 = 20$

$$q_1 p = \frac{6}{2\left(1 - \frac{1}{20}\right)} = 3.15$$

To find how much the yield of this well will be increased by extending it to a depth of 100 feet, we have from (4)

$$Q_1 = 6.30\left(1 - \frac{1}{100}\right) = 6.24$$

The yield of the well would be increased $\frac{1}{4}$ gallon per minute by extending it from 20 to 100 feet depth.

The formula indicates that half the water obtainable will be found in the first foot of depth in shale rocks.

This result is certainly of the right order, since experience shows that nearly all the water obtainable in Hudson River shale is often found within 5 feet below rock surface. A number of wells to depths of over 1000 feet in shale in the vicinity of Albany, N. Y., afford their entire yield very near the surface and refute the popular belief that water can always be found in abundance if only a well is drilled deep enough.

Formula (3) can be applied in a manner similar to (4) to determining the probable increase of yield with depth for wells in granite, etc., and indicates little expectancy of increased yield at depths exceeding a few hundred feet, which also is verified by experience.

Formulas (3) and (4) are intended more especially for application to tunnels and mines rather than to wells, since the surface area of ground water interception in the case of the former is much larger and will generally approximate average conditions more closely than for isolated wells.